CLAIMS

1. A method of characterising a tuneable multi-section semiconductor laser (100) comprising the steps of:

a) applying currents (I_P, I_G, I_R) in step-wise increments to sections (101, 102, 103) of the laser respectively;

b) measuring power output by the laser to determine values (61) of the applied currents corresponding to respective stable operating conditions for which the laser emits radiation at wavelengths remote from mode boundaries (51, 52, 141, 142) of the laser;

c) determining the respective wavelength of the emitted radiation;

d) measuring variations in the applied currents required to cross a mode boundary (51, 52; 141, 142) such that the laser undergoes a mode jump to emit radiation at a wavelength significantly different from that under the respective stable operating condition; and

e) storing in a first look-up table respective values of applied currents (I_P, I_G, I_R) for which the laser emits radiation (104) at wavelengths remote from mode boundaries, the corresponding wavelengths of the radiation and the variations in applied currents required to cross adjacent mode boundaries for use of the laser under the characterising conditions and state of ageing of the laser; and

f) varying the applied currents a plurality of times, to cause predetermined incremental changes in wavelength of the emitted radiation, within the said mode boundaries, and storing further values of applied currents for each predetermined incremental change in wavelength respectively for use as the wavelength of radiation emitted with currently used applied currents changes by more than a predetermined threshold change.

2. A method as claimed in claim 1, wherein the step of storing further values of applied currents comprises storing further look-up tables and the step of using the further values comprises using one of said further look-up tables.

3. A method as claimed in claims 1 or 2, wherein the step of storing further values of applied currents comprises storing further values corresponding to frequencies only in a predetermined range in the vicinity of predetermined required frequencies of emission of the laser.

4. A method as claimed in claim 3, wherein the predetermined range is±10 GHz.

5. A method as claimed in claim 4, wherein the predetermined range is±2 GHz.

6. A method as claimed in claims 3 to 5, wherein the further values corresponding to frequencies in the vicinity of the predetermined frequencies are stored in the first look-up table.

7. A method as claimed in any of the preceding claims, wherein step a) comprises applying currents in step-wise increments using a programmed waveform.

8. A method as claimed in claim 7, wherein the programmed waveform has a frequency of substantially 100 kHz.

9. A method as claimed in claim 7, wherein the programmed waveform has a frequency of substantially 1 MHz.

10. A method as claimed in any of the preceding claims, wherein step d) of measuring the variations comprises deriving the variations by determining distances (l, s) in an applied current plane of a point corresponding to the stable operating condition from adjacent longitudinal mode boundaries and, for a laser having four or more sections, from adjacent super-mode boundaries.

11. A method as claimed in any of the preceding claims, wherein step c) includes the steps of:

c1) providing an optical filter, or feature extraction filter (110), for transmitting a proportion of power of an incident light beam emitted by the laser, the proportion being dependant on the wavelength of the incident light beam; and

c2) measuring the proportion of power transmitted by the filter to determine the wavelength of the emitted radiation.

12. A method as claimed in claim 11, wherein the optical filter comprises multiple passive optical filters.

13. A method as claimed in claims 11 or 12, wherein the optical filter comprises a graded refractive index lens for use as a precision optical filter.

14. A method as claimed in any of the preceding claims, wherein, for a multi-section semiconductor laser having a gain section, a phase section and at least one tuning section, step a) includes the steps of:

a1) applying constant currents to the gain and phase sections such that the laser emits laser radiation; and

a2) applying at least one tuning current in step-wise increments to the at least one tuning section respectively; and

step e) includes storing in the first look-up table the values of the at least one tuning current for which the laser emits radiation at wavelengths remote from mode boundaries.

15. A method as claimed in claim 14, wherein, for a three-section laser, the at least one tuning section comprises a reflector section (103).

16. A method as claimed in any of claims 14 or 15, wherein, for a three-section laser, step a) comprises varying a reflector current (I_R) to determine stable points midway between longitudinal mode boundaries.

17. A method as claimed in any of claims 14 to 16, wherein, for a laser having more than three sections, the at least one tuning section comprises a front section having an applied front current and a back section having an applied back current and step a) comprises holding the front current at a first front constant (1510) and varying the back current, holding the front current at a second front constant (1520) and varying the back current, holding the back current at a first back constant (1530) and varying the front current, holding the back current at a second back constant (1540) and varying the front current, and increasing the front current from a third front constant to a fourth front constant while decreasing the back current from a third back constant to a fourth back constant in order to determine stable middle lines (143) within each super-mode and wherein, having determined the stable middle lines,

subsequent steps of varying the back current and/or the front current respectively comprise varying the respective current through a window of a plurality of incremental values along the stable middle lines and determining for which of the plurality of incremental values the power output is a minimum, and repeatedly incrementing each of the plurality of incremental values and re-determining the current value corresponding to the minimum output power within the window to determine a current value corresponding to a local minimum in the power output.

18. A method as claimed in any of claims 14 to 17, wherein, for a laser having more than three sections, step b) comprises determining midpoints between the current values corresponding to local minima in the power output to obtain stable middle points (61) of operation of the laser and step e) includes storing data representative of such stable middle points together with the corresponding wavelength of emitted laser light in the look-up table and operational conditions for operating the frequencies between the stable middle point frequencies are determined by determining and storing in the look-up table the required values of phase current injected into the phase section of the laser and the required values of phase current are determined by holding the back and front currents constant successively at a first stable point and incrementing the phase current until a frequency of laser emission corresponding to a next stable point is reached and calculating what increments of phase current are required to step from the first stable point to the second stable point in desired frequency increments.

19. A method of controlling a laser characterised by any of the above method steps, and comprising the further step of:

g) determining whether in use the wavelength of radiation emitted by the laser has varied from a characterising wavelength by more than a threshold variation and if so either selecting and using the further values of applied currents to restore the emitted wavelength to a wavelength within the threshold variation or re-characterizing the laser.

20. A method as claimed in claim 19, wherein the step of using the further values of applied currents comprises using one of the further look-up tables.

21. A method as claimed in claims 19 or 20, wherein step g) comprises measuring, at predetermined intervals of time, an offset in the phase current as generated by a frequency-locker feedback-control circuit (105) connected to the laser, to determine whether the offset is excessive and in danger of causing a mode hop; and sufficient to require re-characterisation of the laser which condition may trigger an alarm and, if the offset is excessive but not requiring re-characterisation, identifying and using the further values of applied currents stored when the laser was last characterised and if requiring re-characterisation, re-characterising the laser.

22. A method as claimed in claim 21, wherein the step of determining whether any change in the values is sufficient to require re-characterisation of the laser comprises determining whether the phase current offset is greater than a predetermined value or represents more than a predetermined percentage change.

23. A method as claimed in claims 21 or 22, wherein the frequency locker includes the graded refractive index lens.

24. A method as claimed in any of claims 21 to 23, wherein, the frequency locker includes a Fabry Perot etalon comprising mirrors embedded in slots in a waveguide.

25. A method as claimed in any of the preceding claims of characterising a DS-DBR laser as if it were a collection of a plurality of conventional DBR lasers using the hysteresis property of such lasers.

26. A method as claimed in any of the preceding claims of characterising a tunable laser containing one or more current tunable reflection gratings and a Fabry-Perot cavity wherein the spectra of the grating and a nearby cavity mode overlap to produce a selectable lasing wavelength, the method comprising the steps of:

   a. analysing a resulting hysteresis of longitudinal mode boundaries for meander and span to reject defective lasers; and

   b. identifying longitudinal mode middle lines for best operation to avoid mode hopping; and

c. producing a look-up table of operating currents for desired optical frequencies therefrom.

27. A characterising apparatus for a tuneable multi-section semiconductor laser (100) comprising current drive means for applying currents (I_P, I_G, I_R) in step-wise increments to sections (101, 102, 103) of the laser respectively; power measuring means (1111) for measuring power output by the laser to determine values of the applied currents corresponding to respective stable operating conditions for which the laser emits radiation at wavelengths remote from mode boundaries of the laser; wavelength measuring means (1111, 1112, 1116) for determining a respective wavelength of the emitted radiation; current measuring means for measuring variations in the applied currents required to cross a mode boundary such that the laser undergoes a mode jump to emit radiation at a wavelength significantly different from that under the respective stable operating condition; storage means for storing in a first look-up table respective values of applied currents for which the laser emits radiation at wavelengths remote from mode boundaries, the corresponding wavelengths of the radiation and the variations in applied currents required to cross adjacent mode boundaries for use of the laser under the characterising conditions and state of ageing of the laser and for storing further values of applied currents for each predetermined incremental change in wavelength respectively for use as the wavelength of radiation emitted changes by more than a predetermined threshold within the said mode boundaries.

28. An apparatus as claimed in claim 27, wherein the power measuring means comprises a first photodiode (1111) connectable to the laser by optical waveguide means (1151).

29. An apparatus as claimed in claims 27 or 28, wherein the wavelength measuring means comprises a feature extraction filter (1116) connectable to the laser by optical waveguide means (1115) and a second photodiode (1112) connectable to an output of the feature extraction filter by optical waveguide means.

30. An apparatus as claimed in claim 29, wherein the feature extraction filter (1116) comprises a dielectric multilayer coating on a transparent substrate

located in the optical waveguide means (1115) between the laser (100) and the second photodiode (1112).

31. An apparatus as claimed in any of claims 27 to 30, wherein the wavelength measuring means further comprises a first Fabry Perot etalon filter (1117, 1118) or Fizeau filter, having a first Free Spectral Range (FSR), connectable to the laser by optical waveguide means (1152) and a third photodiode (1113) connectable to an output of the first Fabry Perot etalon filter or Fizeau filter by optical waveguide means.

32. An apparatus as claimed in claim 31, wherein the first FSR is substantially 5 GHz.

33. An apparatus as claimed in claims 31 or 32, wherein the first Fabry Perot etalon filter comprises first and second spaced apart, flat response, dielectric mirrors (1117, 1118) located in the optical waveguide means (1152) between the laser (100) and the third photodiode (1113).

34. An apparatus as claimed in any of claims 27 to 33, wherein the wavelength measuring means further comprises a second Fabry Perot etalon filter (1119, 1120) or Fizeau filter, having a second FSR different from the first FSR, connectable to the laser by optical waveguide means (1153) and a fourth photodiode (1114) connectable to an output of the second Fabry Perot etalon filter by optical waveguide means.

35. An apparatus as claimed in claim 34, wherein the second FSR is substantially 50 GHz.

36. An apparatus as claimed in claim 27 to 33, wherein the wavelength measuring means further comprises a second Fabry Perot etalon filter (1119, 1120) or Fizeau filter, having a second FSR and the first FSR and the second FSR are a same FSR between 50 GHz and 400 GHz and the first Fabry Perot etalon filter (1117, 1118) or Fizeau filter is out of phase by one quarter of the same FSR from the second Fabry Perot etalon filter (1119, 1120) or Fizeau filter so that the first and second filters are in quadrature.

37. An apparatus as claimed in claims 34 to 36, wherein the second Fabry Perot etalon filter comprises third and fourth spaced apart, flat response, dielectric

mirrors (1119, 1120) located in the optical waveguide means (1153) between the laser (100) and the fourth photodiode (1114).

38. An apparatus as claimed in any of claims 27 to 37, wherein the wavelength measuring means further comprises a third Fabry Perot etalon filter, having a third FSR, connectable to the laser by optical waveguide means, and a fifth photodiode connectable to an output of the third Fabry Perot etalon filter, wherein the third FSR provides a local maximum in transmissivity at a same reference frequency as a local maximum in transmissivity provided by the first FSR.

39. An apparatus as claimed in any of claims 27 to 38, wherein at least some of the laser (100), feature extraction filter (1116) and first and second Fabry Perot etalon filters (1117, 1118; 1119, 1120) are interconnected by optical waveguide means (1115, 1151, 1152, 1153) to form a planar lightwave circuit on a substrate.

40. An apparatus as claimed in claim 39, wherein the optical waveguide means is a branched ridge optical waveguide (1115, 1151, 1152, 1153).

41. An apparatus as claimed in any of claims 27 to 40 arranged for characterising a DS-DBR laser as if it were a collection of a plurality of conventional DBR lasers using a hysteresis property of such devices.

42. An apparatus as claimed in any of claims 27 to 41 arranged for characterising tunable lasers containing one or more current tunable reflection gratings and a Fabry-Perot cavity wherein a spectra of the one or more gratings and a mode of the nearby cavity overlap to produce a selectable lasing wavelength; and for analysing a resulting hysteresis of longitudinal mode boundaries for meander and span to detect defective lasers; and for identifying longitudinal mode middle lines for operation avoiding mode hopping to produce a look-up table of operating currents for desired optical frequencies.

43. A computer program comprising code means for performing all the steps of the method of any of claims 1 to 26 when the program is run on one or more computers.